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Dredging Research Technical Notes

Geotechnical Site Investigations for Dredging Projects

Purpose

The objective of a geotechnical site investigation for a dredging project is to obtain the most complete and accurate estimate of the location, description, and dredgeability properties of the sediments to be dredged that is possible within the limits of available time and money and of practicality. This technical note offers guidance in the planning of a dredging site investigation and in the methods typically used for underwater geotechnical investigations. This guidance was developed as part of the U.S. Army Engineer Waterways Experiment Station's (WES) Dredging Research Program.

Background

Subsurface investigations for dredging projects have requirements that are significantly different from those for the typical foundation engineering project. Geotechnical engineering foundation investigations for structures, off- or on-shore, generally cover small areas, sometimes to great depths. Existing land-based techniques and equipment are best suited to serve the primary purpose of performing exacting geotechnical field soils tests and obtaining high-quality samples for laboratory shear strength and compressibility tests. Dredging projects, on the other hand, do not require the knowledge of soil strength and texture with the precision needed for foundation engineering. They do, however, require inferences about the subbottom geotechnical profile over long distances. Average values and ranges of values are generally sufficient.

Additional Information

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Strategy, or Plan, for a Subsurface Investigation

The strategy (plan) for a typical geotechnical site investigation for a dredging project contains the following steps, as illustrated in Figure 1:

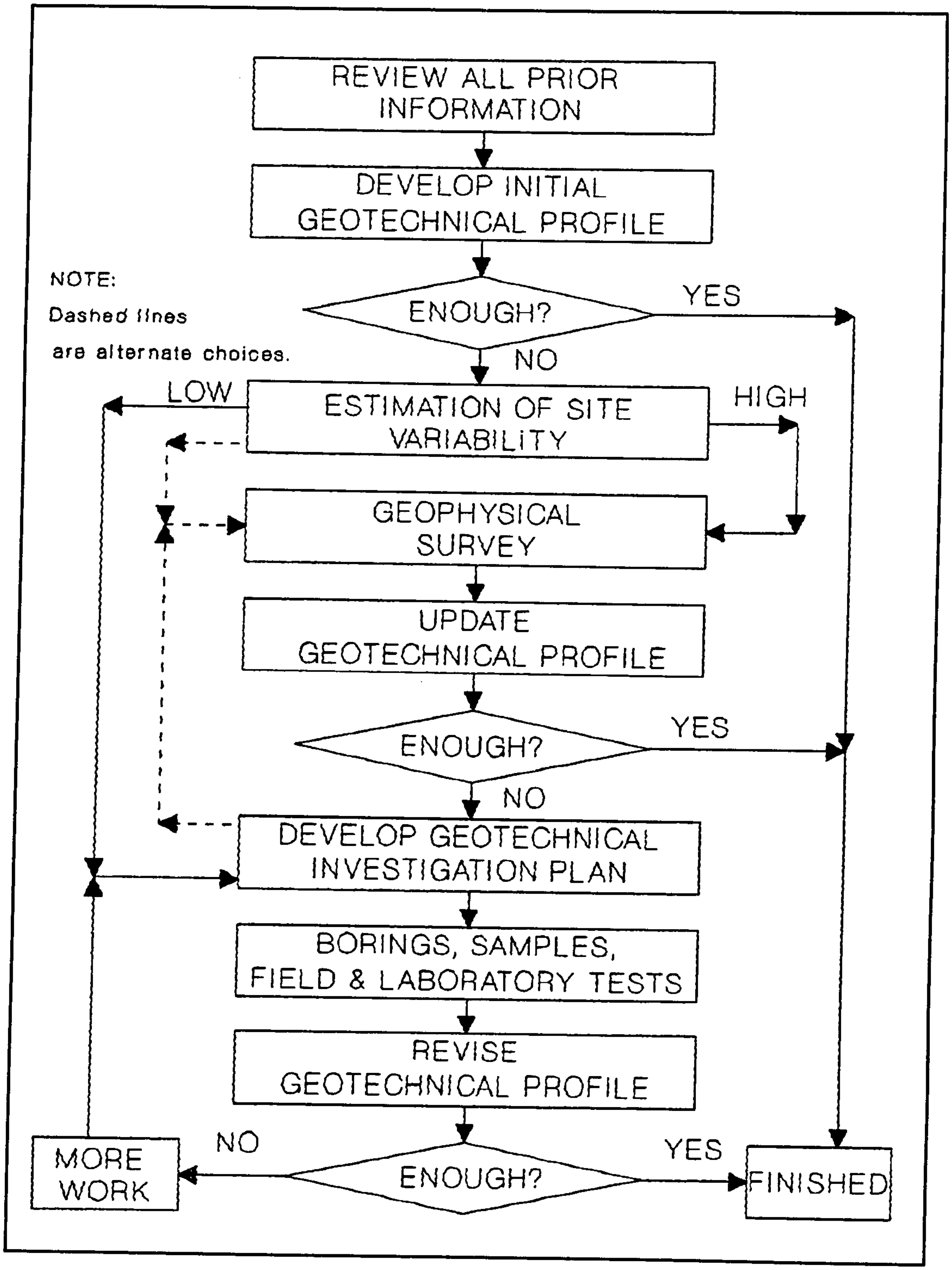

Figure 1. Flow diagram for a dredging subsurface investigation

- A review is made of all available prior (existing) information—the geologic literature, records of previous geotechnical studies in the project area, and personal experiences with soils in the project area. This is sometimes called a literature review or desk study.
- Based on the prior information, an initial estimate of the geotechnical subbottom profile is developed, including the types, configuration, and geotechnical character of the subbottom soils present.
- If the available information is sufficient for the project, the site investigation is terminated at this point. If it is not sufficient, an estimate is made of site variability. If the site is known, from extensive prior information, to be fairly uniform or to vary in a known manner, a site exploration plan is developed. If the site variability is not well known, a geophysical survey may be appropriate.
- Where appropriate, continuous subbottom information is obtained by geophysical studies using acoustic subbottom profiling or other suitable method. The geophysical data are used to amend the initial hypothesis of the soil profile. If the updated geotechnical information is now sufficient for the project, the site investigation is terminated.
- If the amended subsurface profile estimate is still not sufficient, a geotechnical physical site exploration plan is formulated. The number and location of test sites is established tentatively, with the option of changing number and locations as information develops.
- At each exploration site, specific depths and specific methods are selected for sampling and testing the subbottom materials. Sampling depth may be reached by drilling or the digging of pits. Geotechnical samples are then obtained for laboratory tests, and field strength tests are made. Using visual-manual tests, an identifying description is made in the field for each sample. The descriptions are later confirmed in the laboratory or office by further examinations and tests.
- The new geotechnical information is summarized and added to the existing information. The previous estimate of the subsurface profile is reviewed for consistency with the new data and is revised as needed.
- If the revised estimate of the subbottom profile is now sufficient for the project, the site investigation is terminated. However, if more information is required, additional geophysical and/or geotechnical sampling and testing are done. This iteration is continued until a point of sufficiency is reached. See Spigolon (1993b) and the following paragraphs for a discussion of **sufficiency of a site investigation.**

Sources of Prior (Existing) Information

Several sources of geological and geotechnical information exist prior to the current site investigation. These sources, summarized below, should be consulted to form the initial estimate of the subsurface profile.

- *Geologic Data Sources.* Sources of geologic literature, maps, and related information for the project area include the U.S. Geological Survey, the U.S. Department of Agriculture Soil Conservation Service, and State Geological Surveys.
- *Project Records.* The General Design Memorandum for each Corps of Engineers' project contains a summary of the geologic and geotechnical information available for use in the design of that project.
- *Remote Imaging.* Aerial and/or satellite photography, using either visible or nonvisible light waves, and ground probing radar.
- *General Sources.* Libraries, local and regional agencies, and knowledgeable individuals.

Choice of Exploration Sites

After all of the prior information and the results of any geophysical studies have been reviewed for the probable stratification and geotechnical character of the materials within the dredging prism, a general, three-dimensional estimated geotechnical profile of the dredging prism is developed.

Of the total number of borings or test pits that are to be made, an apportionment should be made according to the relative uniformity of the character of each deposit. Ideally, if a deposit were perfectly uniform, only one sample would need to be tested to characterize the entire deposit. Some deposits will have fairly uniform properties over a long distance. Others will have a dramatic change over a short distance.

The total number of test sites needed and the magnitude of the exploration program depend on the savings to be expected in the bid price and reduced claims costs. This is impossible to establish analytically because of the lack of input and is usually affected by budget constraints. However, sufficiency can be established intuitively by conference and agreement between the owner (the U.S. Government) and all of the potential dredging contractors. In this manner, a realistic budget can be established.

Geotechnical Soil Properties Used for Estimating Dredgeability

To characterize the sediments for estimating their dredgeability properties, each deposit of each sediment type should be sampled, examined, and tested for the following (Spigolon 1993a):

- In situ shear strength (defined in terms of cohesive soil consistency, granular soil compactness, and compressive strength of rock).
- Grain size distribution (including the maximum size, the median size, uniformity, and amount of fines).

- Angularity of the coarse grains.
- Plasticity of the fines (defined by the Atterberg limits).
- Organic content (defined by an ash content test or by the Atterberg Liquid Limit Test, before and after drying).
- Presence of nonmineral materials such as vegetation, shells, and debris.

Methods of Sampling

Measurements of in situ strength and in situ density are heavily dependent on tests of the undisturbed material. Practical *undisturbed* sampling can be accomplished *only* in cohesive soils and in rock. In both cases, underwater undisturbed sampling is done by securing a tube sample of a type adapted to the hardness of the sediment, as described below.

- ***Thin Wall Tube Sampler***—used for soft to stiff cohesive soils only; pushed, but not driven or rotated. The sampling tube may, or may not, contain an interior piston that serves to retain the sample by suction.
- ***Core Barrel Sampler***—rotated cutting edge uses embedded diamonds for hard rock; serrated steel edge of tube is used for very hard soils and soft rock.

Tests for material grain properties are dependent only on representative, rather than undisturbed, sampling. There is no technical reason to select one representative sampling method over another, except in the case of fluid mud sampling. Total sampling cost and coordination with a strength testing method are the prime requirements. The most commonly used underwater *representative* samplers are as follows:

- ***Split-Tube Drive Sampler***—thick-walled, split-barrel sampler; driven by a drop hammer; best known is the Standard Penetration Test sampler; used for all nonrock sediments; maximum particle size sampled depends on tube diameter.
- ***Gravity Projectile Sampler***—penetration due to force of drop and the attached heavy weight; penetration depth affected by hardness of soil.
- ***Vibrating Tube Sampler***—entire tube is vibrated; lightweight tube enters sediment by high-frequency cutting action.
- ***Bucket Auger Sampler***—cutting edge on bottom of bucket is rotated into soil or soft rock; highly disturbed sample retained in bucket.
- ***Surface Grab Sampler***—bucket or grab; is lowered to sediment surface and cuts into material using own weight.
- ***Powered Scoop Sampler***—machine-operated bucket or grab; fairly large samples; can retain materials too large for smaller devices.

- *Liquid Slurry Sampler*—used for fluid mud only; side-opening, closed-ended tube permits fluid material to enter along entire height.

Methods of Strength and Density Testing

Direct measures of the in situ shear strength of sediments are made by the following test methods on undisturbed samples:

- ***Unconfined Compression Test of Undisturbed Cohesive Sample.*** This is the standard method for defining the consistency of cohesive soils.
- ***Field Vane Shear Test of Cohesive Soil.*** Simulates an undrained shear test (unconfined compression) on in situ cohesive soil.
- ***Laboratory Vane Shear Test of Undisturbed Cohesive Sample.*** Alternative to unconfined compression; not necessary to extrude sample from tube.
- ***Unconfined Compression Test of Thick Wall Tube Cohesive Sample.*** If soil is not sensitive to remolding, this is a reasonably good approximation of undisturbed compressive strength.
- ***Hand Penetrometer/Torvane Test of Undisturbed Cohesive Sample.*** Rapid, easily made field/laboratory test; useful mainly as check test.
- ***Unconfined Compression Test of Rock Core.*** This is the standard method for defining the strength of rock.

Indirect estimates of the in situ shear strength of sediments are made when appropriate undisturbed or representative sampling is not feasible, such as in granular materials. All indirect tests (described below) are field-made tests of the in situ material, the results of which are correlated with shear strength.

- ***Standard Penetration Test (SPT).*** This is the standard for estimating the compactness of clean sands and fine gravels; uses standard thick-wall tube, drop hammer weight, and hammer drop height.
- ***Dynamic Penetrometer Test, Thick-Wall Tube.*** Similar to SPT but uses a larger diameter tube and heavier drop hammer with shorter drop height; correlation with SPT is not standard.
- ***Dynamic Penetrometer Test, Solid Cone.*** Useful when sample is obtained by other means (does not obtain sample); otherwise, results are same as SPT or larger size dynamic test.
- ***Static Cone Penetration Test (CPT).*** Cone-tipped rod is pushed slowly into sediment by machine; needs heavy reaction weight; required force is correlated with SPT; material type estimated from sleeve friction.
- ***Hand-held Sounding Rod Test.*** Cone-tipped rod is pushed by hand or driven by light drop weight; rough approximation of CPT values; best used to establish thickness of very soft zones or top of very hard stratum.

- *Deceleration Rate of Gravity Projectile.* Using **F = ma**, deceleration rate is function of penetration force, which is function of shear strength. This type of device has not yet been well developed, but has potential of being useful.

- *Penetration Rate of Vibrating Tube Corer.* Using constant vibration rate and tube weight, penetration rate can be correlated with strength. Correlations between penetration rate have not yet been well developed, but have potential of being useful. This device secures continuous sample; therefore, may be very useful when combined with a cone penetration test, either static or dynamic, to indicate strength rather than penetration rate or for calibration.

- *Direct Shear Test of Redensified Sand Sample.* If clean sand sample is redensified to in situ density, direct shear test will give shear strength.

- *Drilling Parameter Recorder Test of Rock.* Strength of rock in situ can be estimated from rotational torque, hydraulic pressure, etc. Although not yet fully developed, this method should serve as a useful continuous probing device to establish where to obtain diamond core samples.

- *Diver-Operated Rebound Hammer Test of Rock.* The amount of rebound of a spring-actuated plunger against the surface of a rock is related to the modulus of elasticity, and indirectly to the strength.

- *Splitting Tensile Test of Rock Core.* Core is compression tested on its curved side rather than planed ends; obviates need to saw ends plane; tensile strength is correlated with rock compressive strength. May be done in the field to assist field engineer/geologist in making rapid decisions about sampling and testing.

- *Point Load Test of Rock Core.* A cone-shaped steel point is forced into a rock core; may be done rapidly in the field. Index is correlated with rock compressive strength. May be done in the field or at field laboratory.

Test methods used to directly determine, or to estimate, the underwater in situ density of sediments include the following:

- *Geophysical Acoustic Impedance*—uses sound waves for acoustic subbottom profile; the speed of an energy wave through sediment is a function of its density; rapid areal survey of subbottom materials.

- *Undisturbed Tube Sample of Cohesive Soil*—laboratory test; excellent for soft to stiff samples of cohesive soils; requires careful transport and handling of sample.

- *Undisturbed Core Barrel Sample of Rock*—excellent for very hard soils and all intact rock.

- *Resuspended Density of Sand*—the in situ density of a recently deposited clean sand is approximated by resedimentation in a laboratory tube.

- *Static Nuclear Gauge*—using a gauge inserted into the undisturbed soil, the attenuation of gamma rays is correlated with density.
- *Towed Nuclear Gauge*—for fluid muds only, a high-intensity nuclear gauge is towed through the mud at a controlled depth to obtain a rapid, continuous density indication over a long distance.

Material Identification Tests

Tests are made, in the laboratory or in the field, for index properties of the sediment that can then be used as indicators of the character and probable engineering behavior of the material. These tests described below.

- *Grain Size Distribution Tests*—use screens (sieves) to measure grain size fractions of materials larger than 0.074 mm (No. 200 screen); use sedimentation (hydrometer test) for finer material size determination.
- *Atterberg Limits Tests*—establish the Liquid Limit and the Plastic Limit of material finer than 0.425 mm (No. 40 screen); affected by clay mineral and clay (-0.002 mm) amount.
- *Organic Content Test*—two common methods are ash content by ignition to high temperature to burn off all organics and loss of Liquid Limit by test on dried sample.
- *Water Content Test*—may be measured by standard oven-drying, Static Nuclear Gauge in situ, and gas-pressure methods using calcium carbide.
- *Specific Gravity of Grains*—used to calculate void ratio, porosity, and degree of saturation (gas content).
- *Visual-Manual Cohesive Soil Tests*—rapid, field estimation of plasticity, toughness, dry strength, and shaking.
- *Visual-Manual Granular Soil Tests*—rapid, field estimation of grain sizes, angularity, shape, and hardness.

During the office/laboratory review of all samples, many samples appear visually and texturally similar in all respects. Therefore, it is only necessary to formally test a few typical samples and describe the remaining, untested samples by means of their similarity to the tested ones.

Equivalence of Test Methods

Two test methods, of different precision, can yield results that are equivalent in value. For equal value, it will be necessary to make a larger number of the less precise tests. The choice of one test method over another becomes one of considering the relative amount of time or money needed to make the required number of tests of each for equivalence.

To understand the equivalence of test methods, it is necessary to look at the concepts of random variation and sampling statistics. All sediment deposits do not have uniform properties; however, they can be characterized by an average, and the dispersion of test values about the average can be calculated as the variance. The dispersion, or variance, is assumed due to random causes only. With distance, the average may *trend* toward other values, sometimes in a continuous function (such as a straight line), sometimes (as in a stratum change) in a discontinuous function. The average may be assumed to be constant within a local area.

If, within a single universe (no trend in average), *all* of the possible sample units are tested for a single parameter using a single test method, all (100 percent) of the test results can be summarized in a frequency histogram such as that shown in Figure 2. If desired, a smooth curve can be drawn to fit the histogram to make analysis simpler. In the real world, both the universe average and its variance can never be known. However, most randomly selected values tend to cluster closely around the average. Using statistical concepts for small samples, described in virtually all statistics textbooks, and the histogram and curve of Figure 2, a number of relevant statements may be made:

- The variance of the distribution of test results from a given test method (Figure 2) includes the *sum* of the random variation of the sediment deposit *and* the random variability (precision) of the test method. Of two test methods

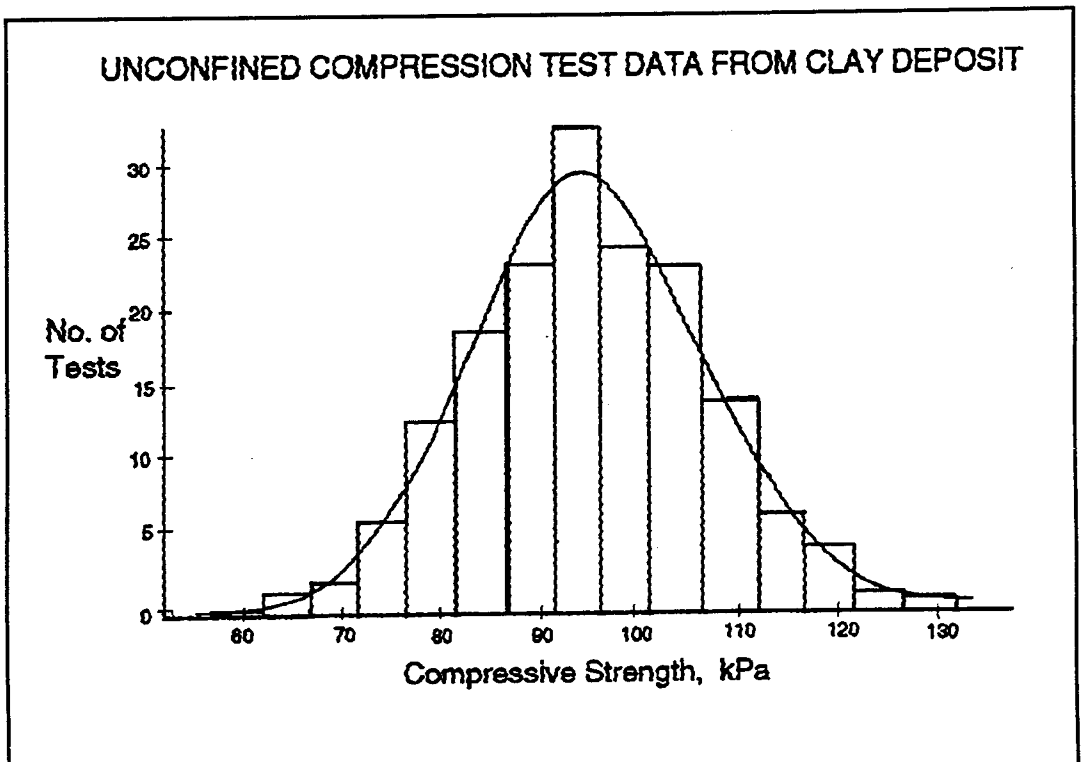

Figure 2. Frequency histogram of unconfined compression tests

used to characterize a deposit, the less precise method will result in a distribution with a higher variance.

- If a very large number of random samples of size n ($n > 4$) are taken from the universe and tested, and the *sample averages* plotted in a histogram, it would have the same shape as shown in Figure 2. The average of the histogram of sample averages is a reasonable estimator of the unknown universe average. The variance (dispersion) of the distribution of sample averages is dependent on the sample size n and on the universe variance (natural variance plus test method variance). The larger the sample size or the smaller the universe variance, the smaller the sampling variance, or dispersion of the sample averages.

- The probability that a random sample, of size n, will have an average larger or smaller than the unknown universe average by a given amount, or deviation, is equal to the relative area under the histogram (or curve) of sample averages to the right, or left, of the deviation value. The value of the probability is directly related to the variance of the distribution of sample averages.

Therefore, when a sample of size n is taken and tested, it is not known how much that sample average differs from the unknown universe average; only the relationship between the magnitude of the difference and the probability that a difference of that size will occur can be inferred. A *confidence interval* can then be established so that the following statement is true: "The probability is x that the unknown true universe average exists within the confidence interval about the sample average."

If sample number 2, of size n_2, using the less precise test method is made sufficiently larger than sample number 1, of size n_1, using the more precise test method, the confidence interval for the two test methods can be made equal at the same probability level and, therefore, the result of using either of the two methods to estimate the universe average is equivalent. Selection, then, should be based only on cost, that is, whichever has the lesser cost, in time and/or money—sample number 1 of size n_1 or sample number 2 of size n_2.

Accessing (Reaching) Sampling/Testing Depth

The depth for obtaining a sample or making a field test can be accessed by borings or by test pits. Borings are either machine- or hand-powered. Borings invariably require casing from the surface to the bottom, and sometimes well into the sediment itself. Borings can be made by auger, continuous flight or hollow-stem, or by rotary drilling using water or mud as the drilling fluid.

Dredging explorations involve underwater sampling and testing at widely separated sites. Therefore, ease of movement is important. Work platforms for supporting equipment and personnel may be floating or bottom

supported. Ships or anchored barges provide a rapid method of movement, but are subject to movements due to wave action. Swell compensators are used, but are costly. Fixed, spud-supported platforms are very stable but are cumbersome to move. Some bottom-supported, surface vessel-operated sampling and testing devices have been developed. These are generally limited in scope and require highly trained personnel. Divers can operate on the surface of the bottom to recover surface samples or to test rock with a rebound hammer.

References

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